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## Security and Privacy Issues in Machine Readable Travel Documents (MRTDs)

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# Security and Privacy Issues in Machine Readable Travel Documents (MRTDs)

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**Abstract.** *After the tragic terror attacks of 9/11, the U.S. Congress resolved to bring about a major overhaul of the immigration process at border posts by passing the Enhanced Border Security and Visa Entry Reform Act of 2002. Section 303(c) of that act requires that countries that participate in the US Visa Waiver Program (VWP) have a program to issue machine readable passports that are tamper resistant and incorporate biometric and document authentication identifiers. In the interest of international reciprocity, the U.S. will issue similar machine readable passports to U.S. citizens. The Technical Advisory Group of the International Civil Aviation Organization (TAG/ICAO) has issued specifications for the deployment of Machine Readable Travel Documents (MRTD) that are equipped with a smart card processor for the purposes of biometric identification of the holder. Some countries, such as the United States, intend to issue machine readable passports that serve only as passports. Other countries, such as the United Kingdom, intend to issue more sophisticated multi-application passports that can also serve as national identity cards. We have conducted a detailed security analysis of these specifications, and we present the results in this paper. We also illustrate possible, hypothetical scenarios that could cause a compromise in the security and privacy of holders of such travel documents.*

## 1 Introduction

The International Civil Aviation Organization (ICAO) has been developing standards for the next generation of passports, the latest version of which was released on 21 May 2004. The most important change in these standards is the prescription for embedding a contactless, smart card processor chip within the passport booklet. The processor will be used to store specific biometrics of the document holder in addition to some personal information. The stored information can then be presented to border control officers at the time of travel. The new passport design is intended to serve two purposes: (a) the biometric information can be used for identity verification at border control, and (b) cryptographic technologies can be used to ascertain the integrity and originality of

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\* Author was a summer intern at IBM Research while this work was being completed

passports, thus preventing very high quality passport forgeries that might otherwise pass a visual inspection.

While the general ideas of these passport standards are clear, and the advantages are obvious, there are inherent problems in the actual design decisions made in the standards. This paper reports the result of our analysis of the standards for the next generation of passports, based on a detailed study of ICAO's specifications for electronic passports and associated standards documents from standards organisations such as the International Standards Organization (ISO) and Federal Information Processing Standards (FIPS).

The paper does not address the political and civil liberties questions of biometric-based identification. That is a question for political debate [12, 30], and this is a technical paper. Rather, the purpose of this paper is to perform a security and privacy vulnerability analysis of those ICAO standards in the context of both the simple passport application and the more complex multi-application credentials. The paper will show that as currently written, the ICAO standards suffer from a number of vulnerabilities that could result in a variety of privacy problems that could lead to identity theft crimes. More seriously, the paper will show vulnerabilities that will permit the exposure of the biometrics of legitimate passport holders to the very criminals that the biometric passports are supposed to protect against. Armed with those biometrics, attackers could possibly gain access to other critical sites that depend on biometric authentication. The paper will show how the ICAO standards could be improved to avoid such problems, using techniques that can be deployed with currently available smart card technology, albeit possibly with an increased cost for each passport.

The primary breach in the security of the electronic passports arises from the invalid assumption that all communications in which a passport chip may participate are secure and legitimate. We will show how this assumption can make it possible to stalk selected passport holders, how it can facilitate identity theft crimes, and how a previous version of the ICAO specification [7, 8] could actually have facilitated passport forgery via a splicing attack. Fortunately, the latest version of the ICAO specification [9, 23] resolves this particular forgery problem, but the stalking and identity theft problems remain.

There are numerous other issues related to the use of both biometrics technologies and smart card electronics with identity documents such as passports. These issues include the debates over the appropriateness of national identity cards, the reliability and longevity of the contactless chips and antennae, whether governments should be able to track the movements of its citizens and visitors, and the reliability of biometrics in general. All of these issues are outside the scope of this report — we focus purely on the security and related technical aspects of using smart cards for electronic identity verification and document integrity verification purposes. Can the smart cards achieve their stated goals while not creating other serious problems, such as identity theft?

The remainder of the report is structured as follows: in §2 we provide a brief overview of ICAO, the organizational body that is responsible for determining the format and structure of the new passports, and we also discuss technological features of the embedded smartchips. We then describe the general use scenario involving these electronic passports at border control posts in §3. In §4, we highlight the security and privacy problems of the current ICAO specifications, using hypothetical examples of

passport tampering and forgery, and make recommendations for changing the specifications to make the new electronic passports immune to the above-mentioned attacks. Finally, we conclude in §7 and enumerate possible directions for future work.

## **2 Machine Readable Documents for International Travel**

### **2.1 Historical Overview**

The International Civil Aviation Organization (ICAO) was formed as a specialized agency of the United Nations Organization in 1946 to promote the safe and orderly development of civil aviation in the world. Their primary purpose is to allow member governments to agree on various standards and protocols of operations for everything related to international civil aviation. Of particular importance to this paper is ICAO's responsibility in setting standards for passports, visas and other travel documents.

ICAO formed a Technical Advisory Group (TAG) on machine readable travel documents (MRTDs) consisting of government representatives from the following 13 member states: Australia, Canada, the Czech Republic, France, Germany, India, Japan, New Zealand, the Netherlands, the Russian Federation, Sweden, the United Kingdom and the United States. These representatives are typically government experts in travel control issues such as immigration, customs, passport issuing, consular services, etc. There is a New Technologies Working Group (NTWG) of TAG/MRTD that has been responsible for the work on smart-card-based biometric passports.

In 2002 the U.S. Congress passed the Enhanced Border Security and Visa Entry Reform Act [44]. Section 303(c) of that act requires that countries that participate in the US Visa Waiver Program (VWP) have a program to issue machine readable passports that are tamper resistant and incorporate biometric and document authentication identifiers that comply with standards established by the International Civil Aviation Organization (ICAO). In the interest of international reciprocity, the U.S. will issue similar machine readable passports to U.S. citizens. 26 October, 2004 was the original deadline for the the 27 VWP nations to comply with this requirement by beginning to issue electronic passports. However, an extension until mid-2005 has been granted [5] by the US Department of Homeland Security to make up for delays in production and procurement, and implementations in practice.

Since January 2003, border control officers have been recording facial images and index fingerprint images for visa-carrying passengers upon arrival at a US border control post. These images are cross-referenced against watch-lists of known criminals. These security measures already helped catch over 30,000 suspected criminals [3] attempting to re-enter the U.S. using fraudulent documents.

### **2.2 Evolution of Machine Readable Travel Documents**

ICAO first introduced the use of machine-readable data printed on passports with Optical Character Recognition (OCR) text on the data page of passports in 1980. This OCR information comprising the Machine-Readable Zone (MRZ) exists in today's passports, and it generally consists of all the information that is already present on the data page,

viz., the document holder's name, date of birth, sex, the actual document's identification numbers, and the various dates signifying the validity period of the travel document. The biggest advantage of the MRZ is that the border control officer can simply wave the open data page of the passport and the data is automatically scanned, thus avoiding having to type in all of the traveller's information.

The next stage in the use of electronically readable information from a printed medium was in the use of 2-D barcodes. These can be used to encode  $\approx 8192$  bytes of information, and are in current use on many passports, visas, and driving licenses. The standards for MRTDs have been published in [27].

ICAO's standards for the next generation MRTD specify [2] a contactless smart card microchip to be embedded within the passport booklet. We discuss the technical aspects of the embedded microchip next.

### **2.3 Embedded Microprocessor Chip**

ICAO prescribes the use of contactless embedded chips conforming to ISO 14443 [14] (also called vicinity cards, vs. contact cards). There are two types of these cards, called Type A and Type B, but the differences [33, section 3.6.3] are in the modulation of the RF signals and small differences in the communications protocols. Both types have central processing units and can carry out cryptographic calculations. These chips will be embedded along with their antennae, which, when brought into an appropriate electromagnetic field, will generate an electric current that can power the chip.

Contactless smart cards and Radio Frequency Identification (RFID) tags are closely related technologies that are often confused. For example, the press often describes the new passports as using RFID technology, whereas the ICAO requirements in fact call for contactless smart cards. The principal distinction is that RFID tags tend to be low-cost low-end devices that can transmit a fixed message, while contactless smart cards typically have complex CPUs and cryptographic capabilities that can do significant amounts of computation. The Smart Card Alliance has published a good summary of the differences between RFID tags and contactless smart cards [34].

Contactless smart cards offer several advantages over contact smart cards, including no wear and tear due to excessive usage, faster data transmission rates, and not needing to change the physical appearance of a passport by adding electrical contacts. However, contactless smart cards have two potential disadvantages. Because the information is transmitted over the air, it may be possible for unintended recipients to intercept information. Second, if many contactless smart cards are physically close together, a reader will have difficulty sorting out which transmission comes from which card. This mutual interference problem is discussed more in section 5.

### **2.4 National Identity Cards**

There have been a variety of proposals to use the ICAO biometric passport technology for national identity cards and other purposes. The United Kingdom began with a proposal for a combined drivers license and passport [18] that has evolved into a full national identity card bill in Parliament [15]. However, the proposal has come under

extensive debate [43], and it is not clear if it will pass this year. Similar projects are underway in a number of countries, including Estonia [42] and Singapore.

### 3 Operation of Electronic Passports

This section describes the envisioned operations of an MRTD in a border post setting. The document holder is expected to present his travel documents to the border control officer who can read the stored data from the chip after exchanging encryption keys for secure communications. The more cryptographically interesting steps in this electronic interaction can be summarized in the following: (a) Basic Messaging and Access Control, and (b) Active Authentication. Basic Messaging serves to setup an encrypted communications channel between the border control reader device and the passport chip, and the Active Authentication phase is used to verify the integrity of the travel document and provide assurance that it has neither been tampered with, nor is a forgery. Each of these steps are discussed in more detail below.

#### 3.1 Passive Authentication

The ICAO specifications have both mandatory and optional security and authentication features. The mandatory features are quite weak, and the optional features are quite limited. The only mandatory requirement is that the information stored on the contactless smart card chip be digitally signed by the issuing country and that the digital signature be checked before use. This requirement is called *passive authentication*, and it provides no protection against unauthorized disclosure of the information.

As originally conceived by ICAO [7, 8], passive authentication suffered from a serious security problem. The 2003 specifications required that the biometrics and the passport holder's name, date of birth, etc. be digitally signed separately.

With only separate signatures, counterfeiting biometric passports is easy. An attacker would get a passport with his/her own identity and biometrics. The attacker would then listen to the communications of a legitimate passport holder and get a copy of the legitimate person's digitally signed identity. The attacker could now create a new smart card with the attacker's biometrics but with the legitimate person's digitally signed identity spliced in. Each signature could be verified by border control personnel, but since the signatures were completely independent, there was no way to detect that the data had been spliced together.

What was missing from the 2003 specifications [7, 8] was a requirement to cryptographically bind the identity of the passport holder together with the biometric. The problem was solved in the 2004 specifications [23, section 2.3.1] by storing hashes of all the fields in the document security object and then having the issuing authority digitally sign the entire document security object (including all the hashes). With the addition of cryptographic binding, splicing becomes impossible, because the hash in the document security object would not match the hash of the false identity. If the attacker tried to change the hash as well as the identity, then the digital signature verification would fail, and the attack would be detected.

Passive authentication provides no protection against skimming or eavesdropping attack by outsiders. A skimming attack is when someone attempts to read the passport chip simply by beaming power at the passport. At normal power ranges, contactless smart card readers must be relatively close to the card within a few inches or at most a few feet. However, that range can be extended if the reader broadcasts power at illegally high levels. A skimming attack could be done to facilitate identity theft or to trace the movements of an individual. A person traveling in a bad neighborhood could be attacked just on the basis of his or her nationality, revealed through skimming.

An eavesdropping attack can occur, if the contactless smart card is actively communicating with a legitimate reader. RF emanations from both the smart card and the reader have been shown in tests to be readable at distances up to 30 feet (9 meters) [35, 47]. The reports of successful eavesdropping at 30 feet do not include any technical details of how the eavesdropping was accomplished. In particular, it is not clear whether special antennas or sophisticated signal processing could increase the range beyond 30 feet.

### 3.2 Basic Access Control

The ICAO standard [23, section 2.4] suggests that some countries might be concerned about unauthorized skimming or eavesdropping and offers a basic access control mechanism as an optional countermeasure. Given that skimming and particularly eavesdropping are possible attacks, countries that choose to implement only passive authentication will leave many of their passport holders vulnerable to attack. However, this section will show that even the basic access control option is not very effective at protecting the sensitive information on the MRTD chip, such as the digitized biometrics.

Basic Access Control requires that the initial interaction between the embedded microchip in the passport and the border control reader include protocols for setting up the secure communication channel. The reader first acquires the MRZ information from the data page of the passport, generally via a connected OCR scanner. This MRZ information is used for computing the encryption and message authentication keys ( $K_{ENC}$  and  $K_{MAC}$ ) used for the “secure” exchange of the session keys. Using information that is available on the actual travel document is intended to limit access to only those people who have been physically shown the passport by the passport holder. Both the reader and the embedded passport chip generate, and exchange random numbers which are then used to create a shared triple-DES session key for encrypted communications.

Basic access control should be effective against simple skimming attacks. If the attacker has no knowledge of who the intended victim is, then the attacker will not know the MRZ information and will not be able to derive the cryptographic keys. However, a more sophisticated attacker who knows something about the intended victim can be more successful.

The MRZ information used for basic authentication is the passport serial number, the holder’s date of birth and the expiration date of the passport. While an attacker who is just trying to skim information off passports of random passers-by would likely not know this information, someone who is trying to target a known person would certainly know at least their date of birth. Since passport serial numbers are usually assigned in sequence, there is likely a high correlation between the serial number and the dates of

issue and expiration. The ICAO's Public Key Infrastructure (PKI) report [23] points out that there is insufficient entropy in these numbers to protect against a serious brute-force attack, in which the attacker tries to guess the serial number and date of expiration. The report dismisses this threat, suggesting that there are easier ways to obtain the information stored on a passport.

However, the report neglects the fact that the biometric information, digitally signed by the appropriate government office is **not** easily obtained from other sources. The digital signature of the biometric particularly increases the value. In addition, the report does not consider the possibility of an attacker seated close to the intended target (perhaps on a train<sup>3</sup>) having a very long period of time to carry out the brute force attack of guessing all possible serial number - expiration date pairs.

However, there are much more serious threats than the brute force attack. The PKI report assumes that anyone who can see the printed material on the passport is allowed to read the biometrics. This is true for border control officers, but many other staff at airports need to see the passport data page, but should not be allowed to read the biometrics. In addition in many countries, passports must also be shown to hotel clerks, and in some countries, may have to be left overnight with the hotel or with local law enforcement agencies. Furthermore, hotel clerks often photocopy the passport data page, and these photocopies will have all the information needed to pass the authentication challenges. A person may have to show their passport when changing money or cashing checks. Hotel clerks and clerks in a bureau de change should not have access to the digitally signed biometrics, but nothing in the ICAO requirements prevents this. This problem is still of limited concern if only the ICAO-required information is stored on the passport, but some countries have announced plans that the passports will become the national ID card to be used for many purposes besides international travel. If the card is your driving license, then the rental car clerks will have access to your biometrics. If it is your medical card, then clerks in pharmacies will have access. As a national ID card, more information will be protected by this inadequate authentication scheme, and the threat of identity theft becomes a very real one.

However, identity theft is not the biggest problem. If an attacker can gain access to fingerprint information stored on the card, then the attacker may be able to create a false finger [28, 29, 41] to be used to attack unattended fingerprint reader systems. This attack could give access to critical locations to the very criminals against whom the biometric passports are supposed to protect.<sup>4</sup>

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<sup>3</sup> Such an attack would be more difficult on an airplane, because of the restrictions on the use of radio frequency electronic equipment.

<sup>4</sup> Of course, attackers can obtain fingerprints by other means, such as lifting a print off of a glass in a restaurant. However, lifting a print is difficult, because the print might be smeared. Getting the digital form of a fingerprint (either a digitized image or minutia) gives the attacker an exact copy of what will be checked in some other biometric access control device. This makes it easier to construct a fake finger that has the correct biometric. Even this doesn't guarantee a usable fake finger, as there are liveness detectors that may be used, but anything that helps the adversary to construct the fake finger should be avoided. The current basic access control does not adequately protect the biometrics. See section 3.4 for a discussion of how ICAO proposes handling this.

### 3.3 Active Authentication

Once the secure communications channel has been created, the reader can verify the integrity of the data stored in the passport chip through the use of a Public Key Infrastructure (PKI). In a nutshell, the reader issues a cryptographic challenge, which is digitally signed by the passport chip. In the reader's view, this digital signature serves to affirm the authenticity of the travel document and that the chip has not been replaced.

Annex G of [23] describes the possibility that the passport could contain a special chip that actually communicates with a remote passport chip using some other network protocol, forwarding the boarder crossing point reader's messages to the other chip. ICAO calls this the "Grandmaster Chess Attack", but Annex G does not make clear how an attacker could gain benefit from such an attack. It only says that the attack cannot be prevented.

In fact, the "Grandmaster Chess Attack" is a commonly used feature of many smart cards, where it is called "cryptographic tunneling". If a card holder wishes to use the card from home to perform some kind of internet commerce, the card holder's home computer would establish a cryptographic tunnel so that the smart card could carry on secure encrypted communications with some other server on the Internet. The difficulty is that there is no easy way to distinguish legitimate uses of cryptographic tunnelling from what ICAO calls the "Grandmaster Chess Attack". For example, if the MRTD was also a national ID card, as proposed by a number of countries, such cryptographic tunneling a.k.a. "Grandmaster Chess Attacks" might be essential to using various government services over the Internet from home!

ICAO should either make clear what the threat of a "Grandmaster Chess Attack" could actually accomplish or else ICAO should view cryptographic tunneling as a useful feature.

### 3.4 Extended Access Control to additional biometrics

In section 3.2 above, we criticized basic access control as being insufficient to protect fingerprint biometrics. This criticism is technically unfair to ICAO, because the PKI technical report realizes that additional biometrics do need additional protection. The problem is that the PKI report leaves this additional protection unspecified, which means that different countries may implement different, mutually-incompatible mechanisms, and that some countries may add biometrics and not do extended access control at all.

Dennis Kügler, of the BSI in Germany, is developing such an extended access control mechanism [25]. It includes an alternative active authentication protocol that replaces the current ICAO authentication and access control schemes to better protect biometrics, such as fingerprints. Kügler's protocol provides mutual authentication between the passport and the reader which is a major improvement. However, Kügler's protocol could be improved in one privacy aspect. Because it calls for the passport to transmit its identity first, this could allow skimmers to track the movements of the passport, and therefore track the movements of the passport holder, thereby reintroducing some of the threats that basic access control prevented. Kügler's protocol could be improved by requiring the reader (rather than the passport) to transmit its identity first, and

permit the passport chip to reject an unauthorized reader without revealing its own identity at all. An example of such a privacy-preserving mutual-authenticating approach is the Caernarvon authentication protocol [38] that is specifically designed to protect the privacy of a smart card holder and is based on the SIGMA family [24] of protocols that form the basis of the Internet Key Exchange Protocol (IKE) [13]. Not only are the SIGMA protocols a widely used standard, they have also been formally proven correct [6]. IBM has chosen not to assert any IP claims on the protocol, to ensure that it can be freely used in standards. As a result, the Caernarvon protocol has been adopted [1] for use by CEN, the European Committee for Standardization.

## 4 Other Weaknesses and Recommendations

### 4.1 Combining traditional attacks with biometrics

There are a host of obvious attacks against the passport-issuing systems that are quite difficult to combat. We mention some of them here, but they are not the focus of the paper. Obviously, the passport issuing system could be attacked by burglars or by people who bribe or threaten the staff to issue false passports. These attacks work against traditional paper passports as well as biometric smart-card based passports. However, if a criminal can bribe or bully an official to issue a false biometric passport, the criminal can now take advantage of human nature. Border crossing personnel are trained to detect false passports. However, human nature is such that if the computer says that biometrics are correct, the immigration official is less likely to question either the passport or the criminal.

### 4.2 Other recommendations

Some conventional cryptographic hashing functions (MD4, MD5, SHA-0) have been demonstrably broken within practical limits. Current ICAO standards specify the use of SHA-1 for all computing hashes. Very recent results [46] suggest that SHA-1 itself has vulnerabilities. As NIST is already phasing out SHA-1 and recommending [31] the use of newer hash algorithms such as SHA-256 [39], etc., the ICAO standards should also require the use of these newer and stronger hashing algorithms.

An alternative to mutual authentication between the reader and the passport chip would be for both to communicate with a mutually trusted third-party. In the case of a shared root certification authority, this third party would be ICAO or the UN. However, finding a third party that all countries could agree upon is likely to be very difficult. In the current proposals, ICAO is providing only a public key directory to find certificates. ICAO is **not** certifying that the certificates are genuine. That is left to individual country certificate authorities [23, section 2.2.2]. However, if we consider an **active** third-party agent, this could be a secured computer owned by the passport holder's native country (or their consulate), but connected to the border control computer network. This way, any certificates that the passport chip inherently trusts (i.e., is already stored on-chip) can be used to verify the identity of the secured computer. If the passport chip can trust the secured computer [36], it can be assured that all its communications with the reader are fresh, i.e., it doesn't have to worry about keeping up-to-date with revocation lists.

## 5 Visas

The ICAO proposals for MRTDs are currently for passports only, and they assume that the chip is written only by the issuing country and that other countries may not store data on the chip. This is necessary, partly because the current level of security available in smart card operating systems is not certified to protect national security against the threat of mutually-hostile applications. The Council of the European Union proposed [32] a biometric visa approach, in which each country affixed its own additional smart card chip in the passport at the time that the visa was issued to the passport holder. With a separate chip per visa-issuing country, there would be no need to provide the security required to permit multiple countries to write to the same smart card chip.

Unfortunately, as the EU investigated this approach to biometric visas, their study group determined [40] that storing multiple contactless smart card chips that close together in a single passport document resulted in a “collision” problem, when trying to read the contents of the chips. The typical contactless smart card reader that would be installed at a border crossing point would be unable to distinguish the communications of one chip from another. As a result, the EU is now considering that each country issue a visa on a smart card, separate from the passport. However, this would be significantly less convenient for the visa holder, and having multiple cards makes it more likely that some of them might be lost or stolen.

An alternate approach would be to use a smart card operating system that was sufficiently strong to permit multiple countries to download their own code and data onto the chip and still maintain security between them. Only two such smart card operating systems exist today. One is MULTOS, developed by Maos Corp. that has been evaluated [4] at the highest level (E6) of the European ITSEC evaluation criteria [17]. However, the evaluated configuration of MULTOS does not permit information sharing between applications which would make sharing data between the passport and the visa applications problematic. The other possibility is IBM’s Caernarvon operating system [21] that is designed to be evaluated at the highest level (EAL7) of the Common Criteria [16]. Caernarvon includes a security model [19, 20, 37] to allow evaluated sharing of information between applications. However, Caernarvon is still only a research project and is not currently available as a product.

## 6 Commentary

### 6.1 Congressional Intent

An important question is whether the ICAO standards meet the intent of the US Congress in the Enhanced Border Security and Visa Entry Reform Act of 2002 [44]. The law itself does not give reasons for its requirements. Congressional intent can only be determined from the debates over the act. In this portion of the debate [45], it is clear that the Senate was most concerned about known terrorists not being detected when they entered the United States and that the 9/11 terrorists had overstayed their visas. While the ICAO standards may technically meet the needs of border crossing authorities, additional concerns arise in the deployment of the proposed technology.

For example, the new technology may facilitate attack on security checkpoints other than those at border crossings, as described in section 3.2.

## **6.2 Protocol Security is Hard**

It is not the intent of this paper to be overly harsh on the process followed by ICAO to develop the standards. Getting wireless security protocols to be secure is a very hard task. From the track record of other major wireless security protocol developments, it is not surprising that ICAO has had problems. Among the protocols that have had similar problems are 802.11 [10], Cellular Digital Packet Data (CDPD) [11], cell phones [26], Intelligent Transport Systems (ITS) [22], and many others. These problems arise, because the designers of a wireless protocol frequently focus on the issues of getting the protocol to work and do not understand many of the subtle security and privacy implications. Such projects need to do comprehensive vulnerability analyses to ensure not only the security of the protocols themselves, but also that side effects of the protocols do not create problems for other systems.

## **7 Conclusion**

A carefully planned and proper implementation of cryptographic and other security measures will undoubtedly improve the security of biometric passports and make them nearly impossible to forge with today's technology. However, ICAO's current plans for smart card-enabled biometric passports include some overly weak protection measures which can end up compromising the security and privacy measures that were meant to be enhanced with the new technology. We have shown how the current ICAO safeguards can be defeated in a number of ways with relatively low-cost technology. Armed with the information stolen from a passport, the criminal can carry out a variety of identity theft crimes, and worse still, an attacker could use the information to construct a false biometric credential that could then be used to breach other biometric access control systems, such as those used to protect airfields, nuclear generating stations, and other critical infrastructure.

We have also shown alternate cryptographic techniques that could be used by ICAO to adequately protect the information on the passport chips without unduly raising deployment costs.

Going beyond biometric passports, we have also shown technical directions that could be taken to support the EU's desire for biometric visas by recommending new high assurance smart card operating system technology that could provide adequate security to allow multiple countries to safely write information to the same smart card chip.

## **8 Acknowledgements**

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